A Methodology for the Development and Integration of Functionally Graded Materials

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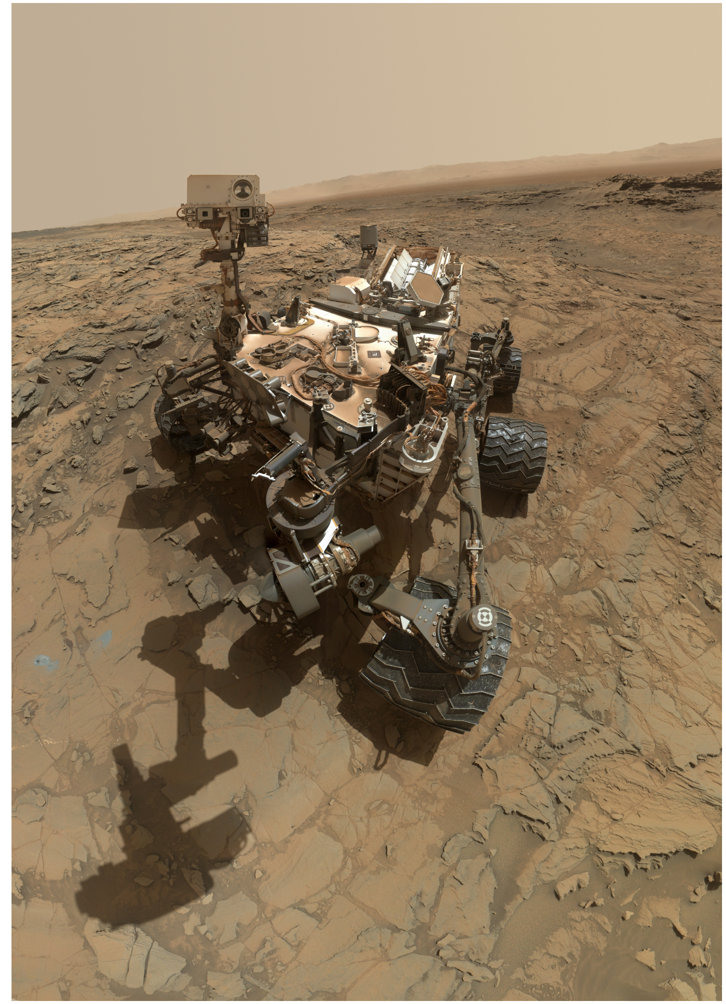
Agenda

1. Background
2. Design Methodology
3. Flight Insertion Approach
4. Acknowledgements



Mars Science Laboratory (Curiosity) /
Mars 2020 (Image JPL/NASA)

Functionally Graded Materials via Additive Manufacturing

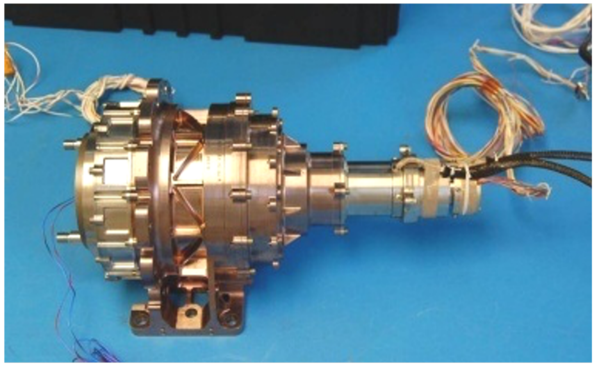
Initial interest sparked by flight issues on Mars Science Laboratory

Need was identified for niche, point solutions for complex environments

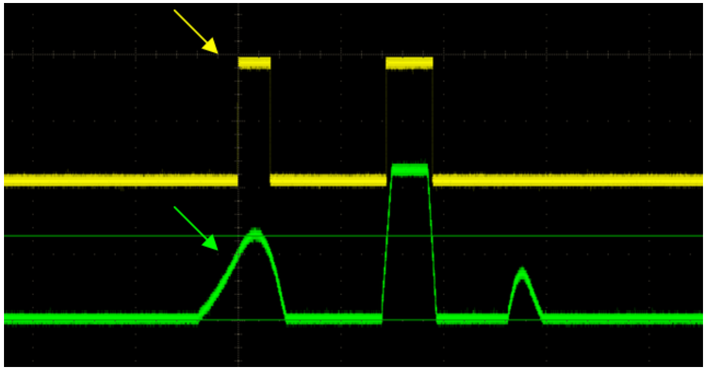
General approach is to look for multi-functional applications, rather than basic structural

Challenges

JPL's missions are generally single build, so total cost cannot be amortized over a single part or part-family



Mars Science Laboratory Actuator, 51 total (Image JPL/NASA)

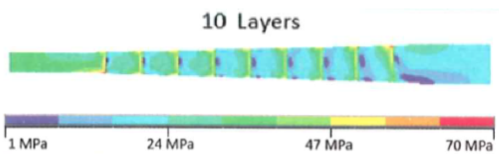


Magnetized C300 Maraging Steel

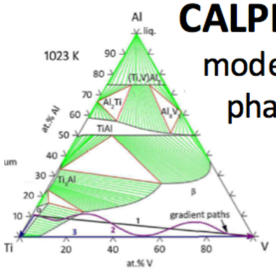
Design Approach

Modeling

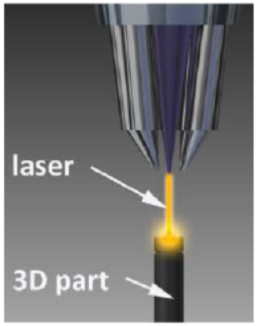
FEA: finite element analysis of residual & thermal stresses



CALPHAD: Thermodynamic modeling of equilibrium phase composition



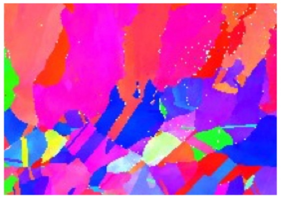
Fabrication



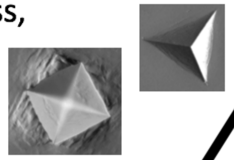
Laser metal deposition of gradient component & post-build **heat treatments**

Characterization

Microstructural:
Optical microscopy & etching,
EBSD + EDS: mapping grain morphology, phase, and texture



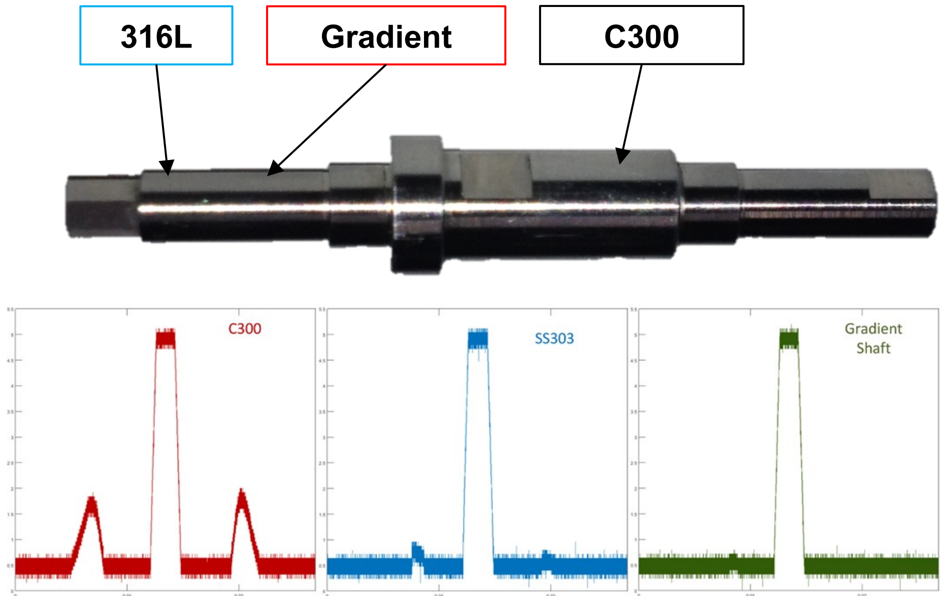
Mechanical properties:
Vickers hardness,
Nanoindentation



Results will help guide future builds.

Qualification Methodology

- ICME
  - First step is multi-stage materials computation looking at residual stress, composition and processing path
- Structural
  - Definition of key properties
    - JPL is specific strength and stiffness driven
    - Few fatigue driven components
  - Destructive analysis of first article
  - 100% proof testing of all flight components
  - Focused materials database
  - Leverage non-destructive testing when possible (next slide)
- Functional
  - 100% part screening for relevant property (right)
  - Proof testing of flight components in relevant environment
  - End-to-end process review to ensure that subsequent flight processing doesn’t alter key properties

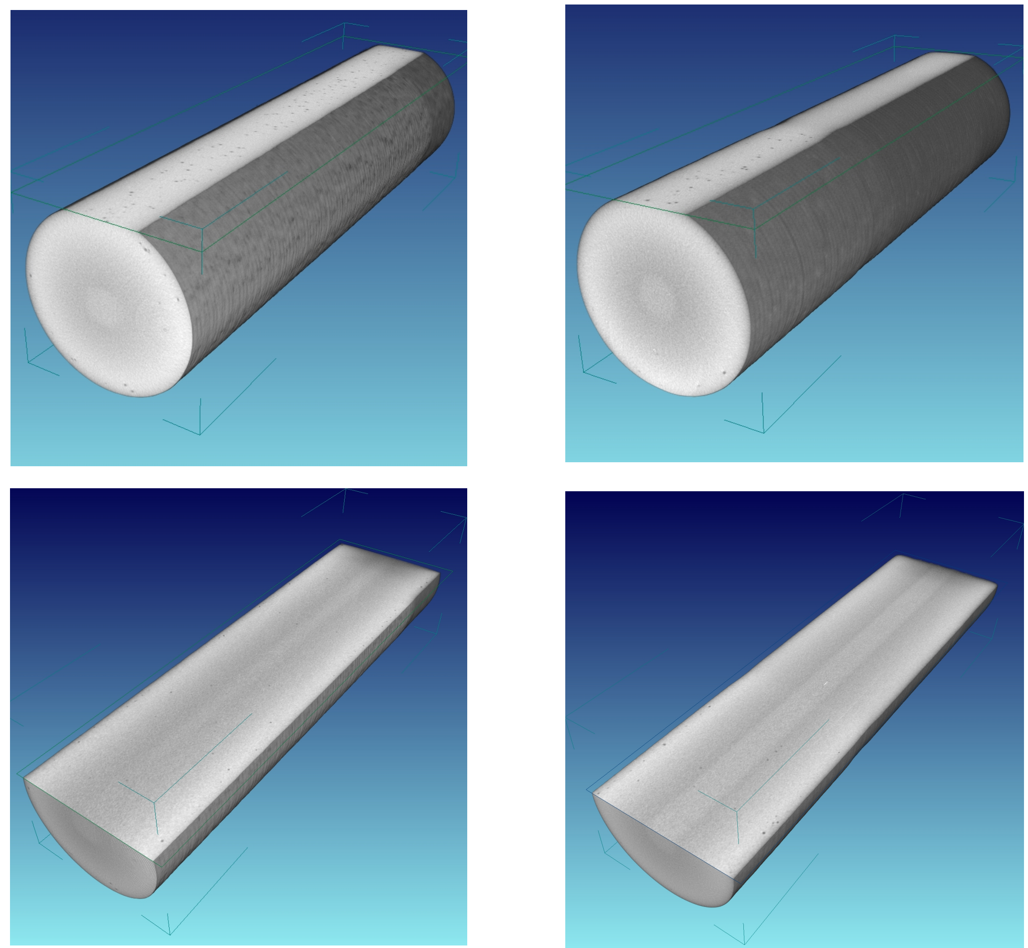


Top: Machined gradient shaft
Bottom: Magnetic characterization demonstrating elimination of magnetic response

Non-destructive Evaluation (NDE)

1. No single NDE approach is universally valid for all part/materials classes
2. Long term approach is leveraging various techniques (e.g. pCRT, computed tomography [at right], radiography) based on NASA-funded work
3. Working with various agencies to have a database of known flaw types and NDE signatures to better select a given technique

Sample geometry is 2.54 cm Ø x 15 cm length



As-built HIP'ped

Conclusions

1. Gradient alloys are currently focused on solving specific design issues for high value applications.
   1. Require significant piece part testing, coupled with materials modeling.
2. Non-destructive evaluation will be critical.
   1. Database of flaws and flaw signatures, coupled with determination of acceptable techniques is critical.
3. Processing requires detailed understanding of microstructures, as each individual layer in the gradient is essentially a unique alloy.
   1. Net effect of properties (structural, functional) needs to be understood, as well as secondary implications (e.g. hot cracking).

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